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[54] **HEAT RESISTANT CAST IRON-NICKEL-CHROMIUM ALLOY**

[75] Inventors: **Junichi Sugitani**, Hirakata; **Teruo Yoshimoto**, Suita; **Makoto Takahashi**, Hirakata, all of Japan

[73] Assignee: **Kubota Ltd.**, Osaka, Japan

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[52] **U.S. Cl.** **420/584**
[58] **Field of Search** .... 75/134 F, 122; 420/584

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Primary Examiner—Veronica O'Keefe
Attorney, Agent, or Firm—Armstrong, Nikaido, Marmelstein & Kubovcik

[57] **ABSTRACT**

A heat resistant cast iron-nickel-chromium alloy outstanding in creep fracture strength at high temperatures and resistance to thermal shock and to carburizing and containing the following components in the following proportions in terms of % by weight:

C—0.3-0.6,
$0<Si\leqq 2.0$,
$0<Mn\leqq 2.0$,
Cr—20-30,
Ni—30-40,
Nb+Ta 0.3-1.5,
W—0.5-3.0,
N—0.04-0.15,
B—0.0002-0.004,
Ti—0.04-0.50 and
Al—0.02-0.50,

the steel further containing 0.2 to 0.8% by weight of Mo when so desired, the balance being substantially Fe.

4 Claims, 3 Drawing Figures

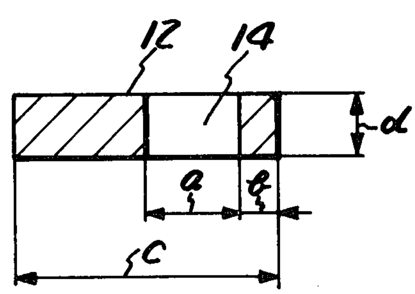


FIG.1

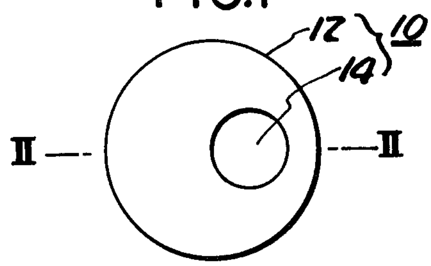


FIG.2

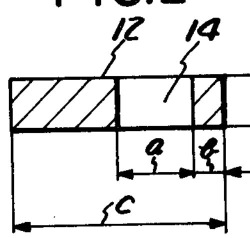
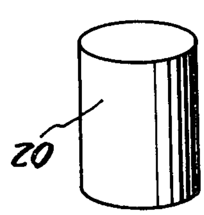


FIG.3



HEAT RESISTANT CAST IRON-NICKEL-CHROMIUM ALLOY

BACKGROUND OF THE INVENTION

The present invention relates to heat resistant cast iron-nickel-chromium alloy, and more particularly to heat resistant cast iron-nickel-chromium alloy which essentially has the composition of austenitic cast alloy containing Cr, Ni, Nb and W and which is excellent in creep fracture strength at high temperatures and in resistance to thermal impact or carburizing.

HK **40** which is a heat resistant cast alloy containing Ni and Cr (25 Cr-20 Ni steel, see ASTM A 608) and HP materials (see ASTM A 297) have been used as materials for ethylene cracking tubes in the petrochemical industries. With the elevation of operating temperatures in recent years, it has been required to improve the high-temperature characteristics of such materials. To meet this requirement, HP materials containing Nb and W or HP materials containing Nb, W and Mo have been developed and placed into use. However, with the recent tendency toward severer operating conditions, it is desired to provide materials which are superior to such HP materials containing Nb and W, or Nb, W and Mo in respect of high-temperature creep fracture strength and resistance to thermal shock or carburizing.

SUMMARY OF THE INVENTION

In view of the above demand, we have conducted intensive research on the influence of variously contained elements on the high-temperature characteristics of heat-resisting cast alloy containing Cr, Ni, Nb and W as the essential components and found that the alloy can be remarkably improved in high-temperature creep fracture strength and resistance to thermal shock and to carburizing by containing N, B, Ti and Al therein, with further use of Mo when desired. Thus this invention has been accomplished.

Stated specifically, the present invention provides a heat resistant cast iron-nickel-chromium alloy containing about 0.3 to 0.6% (by weight, the same as hereinafter) of C, up to about 2.0% of Si, up to about 2.0% of Mn, about 20 to 30% of Cr, about 30 to 40% of Ni, about 0.3 to 1.5% of Nb+Ta, about 0.5 to 3.0% of W, about 0.04 to 0.15% of N and about 0.0002 to 0.004% of B, the steel also containing about 0.04 to 0.15% of Ti and about 0.02 to 0.07% of Al, or about 0.04 to 0.50% of Ti and about 0.07 to 0.50% of Al, the alloy further containing about 0.2 to 0.8% of Mo when desired, the balance being substantially Fe.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a plan view showing a test piece to be tested for resistance to thermal shock;

FIG. **2** is a view in section taken along the line II—II in FIG. **1**; and

FIG. **3** is a perspective view showing a test piece to be tested for resistance to carburizing.

DETAILED DESCRIPTION OF THE INVENTION

In the description to follow, the percentages are all by weight.

The heat resistant cast iron-nickel-chromium alloy of the present invention contains the following components in the following proportions in terms of % by weight:

C—0.3-0.6,
O<Si≦2.0,
O<Mn≦2.0,
Cr—20-30,
Ni—30-40,
Nb+Ta 0.3-1.5,
W—0.5-3.0,
N—0.04-0.15 and
B—0.0002-0.004,

the steel also containing Ti and Al in the combination of:

{	Ti	0.04-0.15 and
	Al	0.02-0.07,
		or
{	Ti	0.04-0.50 and
	Al	0.07-0.50,

the steel further containing when desired:

Mo—0.2-0.8,

the balance being substantially Fe.

In the course of the research which has matured to the present invention, we have also found a heat resistant cast alloy containing the following components in the following proportions in terms of % by weight:

C—0.3-0.6,
O<Si≦2.0,
O<Mn≦2.0,
Cr—20-30,
Ni—30-40,
Nb+Ta 0.3-1.5,
N—0.04-0.15,
Ti—0.04-0.50,
Al—0.02-0.50,
B—0.0002-0.004 and
Fe—balance.

This heat resistant cast alloy, although free from W and Mo unlike the cast iron-nickel-chromium alloy of the invention, has higher creep fracture strength at high temperatures than the iron-nickel-chromium alloy of the invention.

In respect of resistance to thermal shock, the alloy is superior to the conventional HP materials but is slightly inferior to the cast iron-nickel-chromium alloy of the invention. Under conditions in which both features of good creep fracture strength and satisfactory resistance to thermal shock are required, the cast iron-nickel-chromium alloy of this invention is generally preferable to use.

The components of the cast iron-nickel-chromium alloy of the invention and the proportions of the components will be described below in detail.

C imparts good castability to cast steel or alloy, forms primary carbide in the presence of the Nb to be described later and is essential in giving enhanced creep fracture strength. At least about 0.3% of C is therefore required. With the increase of the amount of C, the creep fracture strength increases, but if an excess of C is present, an excess of secondary carbide will precipitate, resulting in greatly reduced toughness and impaired weldability. Thus the amount of C should not exceed about 0.6%.

Si serves as a deoxidant during melting of the components and is effective for affording improved anti-carburizing properties. However, the Si content must be up to about 2.0% or lower since an excess of Si will lead to impaired weldability.

Mn functions also as a deoxidant like Si, while S in molten steel is effectively fixed and rendered harmless by Mn, but a large amount of Mn, if present, renders the steel less resistant to oxidation. The upper limit of Mn content is therefore about 2.0%.

In the presence of Ni, Cr forms an austenitic cast iron-nickel-chromium structure, giving the iron-nickel-chromium improved strength at high temperatures and increased resistance to oxidation. These effects increase with increasing Cr content. At least about 20% of Cr is used to obtain a steel having sufficient strength and sufficient resistance to oxidation especially at high temperatures of at least about 1000° C. However, since the presence of an excess of Cr results in greatly reduced toughness after use, the upper limit of the Cr content is about 30%.

As described above, Ni, when present conjointly with Cr, forms an austenitic cast iron-nickel-chromium of stabilized structure, giving the alloy improved resistance to oxidation and enhanced strength at high temperatures. To make the alloy satisfactory in oxidation resistance and strength especially at high temperatures of at least about 1000° C., at least about 30% of Ni must be used. Although these two properties improve with the increase of the Ni content, the effects level off when the Ni content exceeds about 40%, hence economically unfavorable, so that the upper limit of the Ni content is about 40%.

Nb is effective in improving creep fracture strength and anti-carburizing properties, provided that at least about 0.3% of Nb is used. On the other hand, when containing an excess of Nb, the iron-nickel-chromium alloy will have decreased creep fracture strength. The upper limit of the Nb content is therefore about 1.5%. Usually Nb inevitably contains Ta which has the same effect as Nb. When Nb contains Ta, accordingly, the combined amount of Nb and Ta may be about 0.3 to 1.5%.

When in combination with Nb, W contributes to the improvement of strength at high temperatures. At least about 0.5% of W is used for this purpose, but the upper limit of the W content is about 3.0% since use of larger amounts of W leads to reduced resistance to oxidation.

The iron-nickel-chromium alloy of this invention has the greatest feature in that it contains specified amounts of N, Ti, Al and B, in addition to the foregoing elements. When desired, the iron-nickel-chromium alloy further contains Mo. These elements, when used conjointly, produce remarkably improved characteristics at high temperatures. This effect is not achievable if any one of N, Ti, Al and B is absent.

N serves in the form of a solid solution to stabilize and reinforce the austenitic phase, forms a nitride and carbonitride with Ti, etc., produces refined grains when finely dispersed in the presence of Al and B and prevents grain growth, thus contributing to the improvement of high-temperature strength and resistance to thermal shock. It is desired that the N content be at least about 0.04% to achieve these effects sufficiently. Preferably the upper limit of the N content is about 0.15% since the presence of an excess of N permits excessive precipitation of nitride and carbonitride, formation of coarse particles of nitride and carbonitride and impairment of resistance to thermal shock.

When combining with C and N in steel or alloy, Ti forms a carbide, nitride and carbonitride, thereby affording improved high-temperature strength and enhanced resistance to thermal shock. Especially Ti acts synergistically with Al, producing enhanced anti-carburizing properties. It is preferable to use at least about 0.04% of Ti to assure these effects. While improvements are achieved in creep fracture strength, resistance to thermal shock and anti-carburizing properties with the increase of the Ti content, use of a large amount of Ti results in coarse particles of precipitates, an increased amount of oxide inclusions and somewhat reduced strength. Accordingly, when high strength is essential, the upper limit of the Ti content is preferably about 0.15%. Further when the Ti content exceeds about 0.5%, greatly reduced strength will result, so that the Ti content should not exceed about 0.5% even if resistance to carburizing is critical.

Al affords improved creep fracture strength and, when present conjointly with Ti, achieves a remarkable improvement in resistance to carburizing. Preferably at least about 0.02% of Al should be used to give improved creep fracture strength. Although higher strength at high temperatures and higher resistance to carburizing will result with increasing Al content, use of an excess of Al conversely leads to reduced strength. Accordingly when strength at high temperatures is essential, the upper limit of the Al content is preferably about 0.07%. However, when it is desired to obtain a steel which is comparable to conventional HP materials in high-temperature strength but has improved anti-carburizing properties, amounts at least larger than about 0.07% are desirable. Nevertheless extremely decreased strength will result if the Al content exceeds about 0.5%. Accordingly the Al content should not be higher than about 0.5%.

B serves to form reinforced grain boundaries in the matrix of steel, prevents formation of coarse particles of Ti precipitates but permits precipitation of fine particles thereof and retards agglomeration of particles of precipitates, thereby affording improved creep fracture strength. For this purpose it is desirable to use at least about 0.0002% of B. On the other hand, use of a large amount of B does not result in a corresponding increase in strength and entails reduced weldability. Preferably, therefore, the upper limit of the B content is about 0.004%.

Mo, which is used when required, contributes to the improvement in high-temperature strength if used in combination with Nb and W. To produce this effect, Mo is used in an amount of at least about 0.2%. However, if a large excess of Mo is present, lower resistance to oxidation will result, so that Mo, when used, is used in an amount of up to about 0.8%.

Impurities, such as P and S, may be present in amounts which are usually allowable for alloys of the type described.

The high-temperature characteristics of the cast iron-nickel-chromium alloy of this invention will be described below in detail with reference to examples.

Cast alloys of various compositions were prepared in an induction melting furnace (in the atmosphere) and made into ingots (136 mm in outside diameter, 20 mm in wall thickness and 500 mm in length) by centrifugal casting. Tables 1, 3, 5 and 7 show the chemical compositions of the alloy specimens thus obtained.

Test pieces were prepared from the steel specimens and tested for creep fracture strength, resistance to thermal shock and resistance to carburizing by the following methods.

Test 1: Creep fracture test

According to JIS Z 2272 under the following two conditions:

(A) Temeprature 1093° C., load 1.9 kgf/mm^2

(B) Temperature 850° C., load 7.3 kgf/mm^2

Test 2: Thermal shock resistance test

FIGS. **1** and **2** show a test piece (**10**) used which was made in the form of a disc (**12**) having a hole (**14**) at an eccentric position thereof. Each of letters designated in FIG. **2** indicates the dimension of the test piece (**10**) as follows:

a . . . 20 mm in diameter
b . . . 7 mm
c . . . 50 mm in diameter
d . . . 8 mm

The procedure of heating the test piece at 900° C. for 30 minutes and thereafter cooling the test piece with water at temperature of about 25° C. was repeated. Every time this procedure was repeated 10 times, the length of the crack occurring in the test piece was measured. The resistance to thermal shock was expressed in terms of the number of repetitions when the length of the crack reached 5 mm.

Test 3: Carburizing resistance test

FIG. **3** shows a test piece (**20**) used which was made in the cylindrical form (12 mm in diameter and 60 mm in length).

After holding the test piece in a solid carburizer (Durferrit carburizing granulate KG 30, containing $BaCO_3$) at a temperature of 1100° C. for 300 hours, a 1-mm-thick surface layer (hereinafter referred to as "layer **1**") was removed from the test piece by grinding to obtain particles. The resulting surface of the test piece was further ground to remove another 1-mm-thick layer (to a depth of 2 mm from the original surface, hereinafter referred to as "layer **2**") to obtain particles. The particles of each layer were analyzed to determine the C content. The resistance to carburizing is expressed in terms of the increment (%) of the C content.

The carburizing resistance test was conducted only for the alloy specimens shown in Tables 5 and 7.

The results of the foregoing tests are listed in Table 2, 4, 6 or 8, and will be described in the following examples:

EXAMPLE 1

Of the alloy specimens listed in Table 1, Specimens No. 1 to No. 4 are according to the invention and contain about 0.04 to 0.15% of Ti and about 0.02 to 0.07% of Al but are free from Mo. Specimens No. 5 to No. 20 are comparison alloys, of which Specimen No. 5 is a HP material containing Nb and W, Specimens No. 6 to No. 12 are free from at least one of Ti, Al and B, and Specimens No. 13 to No. 20 contain N, Ti, Al and B in amounts outside the foregoing ranges specified by the invention.

Table 2 shows the results of the creep fracture test and thermal shock resistance test. Specimens No. 1 to No. 4 have exceedingly higher creep fracture strength at high temperatures than Specimen No. 5, i.e. Nb- and W-containing HP material which is considered to be excellent in such strength and the other comparison alloys. The comparison steels which are free from at least one of N, Ti, Al and B or contain these elements in excessive or insufficient amounts are inferior in creep fracture strength. This indicates that the outstanding characteristics can be obtained only when these elements are conjointly present in amounts within the specified ranges. It is especially noteworthy that the steels of this invention exhibit much higher creep fracture characteristics at high temperatures above 1000° C., e.g. at 1093° C., than at temperatures below 1000° C., e.g. at 850° C.

It is also noted that the iron-nickel-chromium alloys of the invention have much higher resistance to thermal shock than the HP material containing Nb and W and the other comparison alloys. The remarkable resistance is of course attributable to the conjoint use of N, Ti, Al and B.

TABLE 1

Spec. No.	Chemical compositions of alloy specimens (wt. %) C	Si	Mn	Cr	Ni	Nb + Ta	W	N	Ti	Al	B	Remarks	
1	0.46	1.21	0.63	25.82	35.02	1.27	1.13	0.09	0.05	0.03	0.0010	With N, Ti, Al, B contents	The invention
2	0.45	1.28	0.72	25.90	35.08	1.28	1.09	0.08	0.07	0.04	0.0021	With N, Ti, Al, B contents	
3	0.43	1.24	0.70	26.89	34.67	1.15	1.08	0.10	0.10	0.07	0.0032	With N, Ti, Al, B contents	
4	0.45	1.20	0.65	26.78	35.16	1.24	1.10	0.13	0.09	0.07	0.0025	With N, Ti, Al, B contents	
5	0.44	1.27	0.65	26.01	35.40	1.21	1.05	—	—	—	—	HP mat. with Nb, W contents	Comparison
6	0.43	1.23	0.76	26.52	35.11	1.17	1.11	0.08	—	—	—	Ti-, Al-, B-free	
7	0.43	1.25	0.73	25.74	35.17	1.15	1.15	0.08	0.04	—	—	Al-, B-free	
8	0.44	1.20	0.62	25.70	35.32	1.27	1.02	0.09	0.13	—	—	Al-, B-free	
9	0.42	1.19	0.78	26.11	35.37	1.22	0.99	0.10	—	0.03	—	Ti-, B-free	
10	0.43	1.17	0.76	26.27	35.07	1.14	1.06	0.10	—	0.07	—	Ti-, B-free	
11	0.43	1.24	0.70	26.51	35.19	1.14	1.06	0.09	0.06	0.03	—	B-free	
12	0.45	1.26	0.61	26.07	35.21	1.24	1.10	0.08	0.10	0.06	—	B-free	
13	0.45	1.26	0.70	26.21	35.07	1.20	1.11	0.09	0.03	0.05	0.0016	Ti deficient	
14	0.45	1.17	0.66	26.17	35.12	1.27	1.02	0.10	0.19	0.06	0.0012	Ti excessive	
15	0.43	1.22	0.68	26.27	34.92	1.27	1.07	0.08	0.08	0.01	0.0010	Al deficient	

TABLE 1-continued

Spec. No.	Chemical compositions of alloy specimens (wt. %) C	Si	Mn	Cr	Ni	Nb + Ta	W	N	Ti	Al	B	Remarks
16	0.44	1.27	0.67	26.20	34.87	1.19	1.14	0.08	0.07	0.11	0.0012	Al excessive
17	0.43	1.19	0.67	26.19	35.10	1.15	1.12	0.10	0.07	0.05	0.0001	B deficient
18	0.43	1.18	0.69	26.15	35.02	1.26	1.10	0.10	0.08	0.05	0.0049	B excessive
19	0.44	1.17	0.67	26.25	35.21	1.26	1.11	0.03	0.09	0.06	0.0015	N deficient
20	0.44	1.25	0.72	26.09	35.11	1.18	1.08	0.18	0.09	0.06	0.0021	N excessive

TABLE 2

Spec. No.	Test results: Creep fracture strength (kgf/mm^2) Condition (A)	Condition (B)	Resistance to thermal shock (times)	Remarks
1	202	156	320	Invention
2	221	167	350	"
3	250	179	360	"
4	246	172	—	"
5	80	73	150	Comparison
6	91	83	140	"
7	113	105	190	"
8	127	116	210	"
9	115	104	170	"
10	131	114	190	"
11	133	110	240	"
12	143	122	280	"
13	88	83	—	"
14	127	105	—	"
15	92	84	—	"
16	119	100	—	"
17	103	77	—	"
18	125	113	—	"
19	92	79	210	"
20	154	137	130	"

EXAMPLE 2

Of the alloy specimens shown in Table 3, Specimens No. 21 to No. 24 are according to the invention and contain Ti, Al and Mo within the ranges of about 0.04 to 0.15% Ti, about 0.02 to 0.07% Al and about 0.2 to 0.8% Mo. Of Specimens No. 25 to No. 40 prepared for comparison, Specimen No. 25 is a HP material containing Nb, W and Mo, Specimens No. 26 to No. 32 are free from at least one of Ti, Al and B, and Specimens No. 33 to No. 40 contain N, Ti, Al and B in amounts outside the ranges specified in this invention.

Table 4 shows the results of creep fracture test and thermal shock resistance test.

Table 4 reveals that as is the case with Example 1, the iron-nickel-chromium alloys of the invention have exceedingly higher creep fracture characteristics and resistance to thermal shock than the HP material containing Nb, W and Mo and the other comparison alloys due to the conjoint presence of N, Ti, Al and B.

TABLE 3

Spec. No.	Chemical compositions of alloy specimens (wt. %) C	Si	Mn	Cr	Ni	Nb + Ta	W	Mo	N	Ti	Al	B	Remarks	
21	0.44	1.20	0.64	25.17	36.20	1.28	1.02	0.48	0.11	0.04	0.03	0.0008	With N, Ti Al, B contents	The invention
22	0.43	1.23	0.69	25.98	35.76	1.23	1.09	0.42	0.09	0.07	0.05	0.0019	With N, Ti Al, B contents	
23	0.45	1.23	0.77	25.73	35.19	1.19	1.13	0.43	0.08	0.12	0.07	0.0032	With N, Ti Al, B contents	
24	0.44	1.21	0.75	26.02	35.08	1.15	1.10	0.41	0.14	0.08	0.07	0.0025	With N, Ti Al, B contents	
25	0.42	1.20	0.71	26.12	35.37	1.29	1.10	0.42	—	—	—	—	HP mat. with Nb, W, Mo contents	Comparison
26	0.43	1.17	0.72	26.24	35.82	1.11	1.07	0.39	0.09	—	—	—	Ti-, Al, B-free	
27	0.43	1.26	0.79	25.97	36.07	1.27	1.05	0.37	0.08	0.05	—	—	Al-, B-free	
28	0.45	1.31	0.68	25.81	35.51	1.25	0.97	0.46	0.09	0.12	—	—	Al-, B-free	
29	0.44	1.28	0.65	26.37	35.11	1.20	1.11	0.45	0.07	—	0.02	—	Ti-, B-free	
30	0.44	1.32	0.65	26.46	35.55	1.20	1.07	0.32	0.08	—	0.06	—	Ti-, B-free	
31	0.45	1.26	0.71	26.15	36.12	1.19	1.06	0.40	0.10	0.05	0.03		B-free	
32	0.46	1.21	0.73	26.33	36.23	1.28	1.06	0.41	0.08	0.09	0.07		B-free	
33	0.44	1.21	0.75	26.07	36.21	1.17	1.08	0.43	0.09	0.02	0.06	0.0015	Ti deficient	
34	0.44	1.25	0.77	26.12	35.92	1.19	1.11	0.41	0.08	0.20	0.07	0.0017	Ti excessive	
35	0.45	1.31	0.67	26.15	35.87	1.24	1.06	0.39	0.09	0.08	0.01	0.0018	Al deficient	
36	0.43	1.28	0.65	25.95	36.07	1.25	1.06	0.39	0.10	0.09	0.12	0.0021	Al excessive	
37	0.43	1.22	0.69	25.89	35.23	1.20	1.13	0.42	0.11	0.09	0.05	0.0001	B deficient	
38	0.45	1.22	0.70	26.34	35.35	1.15	1.17	0.42	0.10	0.07	0.07	0.0055	B excessive	
39	0.44	1.30	0.72	26.27	35.18	1.21	1.10	0.45	0.02	0.09	0.06	0.0016	N deficient	
40	0.45	1.25	0.67	26.19	35.08	1.24	1.11	0.41	0.19	0.10	0.07	0.0022	N excessive	

TABLE 4

Spec. No.	Test results: Creep fracture strength (kgf/mm^2) Condition (A)	Condition (B)	Resistance to thermal shock (times)	Remarks
21	213	164	310	Invention
22	233	176	350	"
23	264	189	380	"
24	259	181	—	"
25	85	77	160	Comparison
26	96	87	130	"
27	120	111	200	"
28	134	123	230	"
29	122	110	180	"
30	138	121	210	"
31	141	116	250	"
32	151	129	230	"
33	88	87	—	"
34	125	111	—	"
35	92	88	—	"
36	131	105	—	"
37	95	82	—	"
38	138	120	—	"
39	97	84	240	"
40	162	144	140	"

EXAMPLE 3

Of the alloy specimens shown in Table 5, Specimens No. 41 to No. 44 are according to the invention. These specimens contain Ti and Al within the ranges of about 0.04 to 0.50% Ti and about 0.07 to 0.50% Al but are free from Mo. Of Specimens No. 45 to No. 49 prepared for comparison, Specimen No. 45 is a HP material containing Nb and W (but free from any of N, Ti, Al and B), and Specimens No. 46 to No. 49 contain N, Ti, Al and B in amounts outside the foregoing ranges specified by this invention.

Table 6 shows the results of creep fracture test, thermal shock resistance test and carburizing resistance test.

The iron-nickel-chromium alloys of the invention prepared in this example are lower than those in Examples 1 and 2 in creep fracture strength and thermal shock resistance because they have higher Ti and Al contents but, nevertheless, they are much superior in high-temperature creep fracture strength and resistance to thermal shock, to the Nb- and W-containing HP material, i.e. Specimen 45, which is considered to be higher in high-temperature creep fracture strength than other conventional alloys, the iron-nickel-chromium alloys of the invention further similarly superior to the other comparison steels.

The carburizing resistance listed in Table 6 is expressed in terms of weight percent increment of C content. Thus the smaller the value, the smaller is the increment and the higher is the resistance to carburizing.

Table 6 reveals that Ti and Al act synergistically to give the iron-nickel-chromium alloys of the invention sufficient creep fracture strength and thermal shock resistance and outstanding resistance to carburizing.

TABLE 5

Spec. No.	Chemical compositions of alloy specimens (wt. %): C	Si	Mn	Cr	Ni	Nb + Ta	W	N	Ti	Al	B	Remarks
41	0.45	1.21	0.70	25.72	35.06	1.15	1.10	0.08	0.20	0.15	0.0023	The invention
42	0.44	1.19	0.66	25.63	35.12	1.20	1.07	0.07	0.17	0.19	0.0020	"
43	0.44	1.27	0.67	26.20	34.87	1.19	1.14	0.08	0.07	0.11	0.0012	"
44	0.45	1.20	0.71	25.77	35.18	1.25	1.17	0.08	0.08	0.12	0.0017	"
45	0.44	1.27	0.65	26.01	35.40	1.21	1.05	—	—	—	—	Comparison
46	0.43	1.28	0.72	26.07	35.15	1.11	1.15	0.07	0.02	0.12	0.0015	"
47	0.44	1.12	0.70	26.08	34.62	1.27	1.10	0.07	0.56	0.11	0.0018	"
48	0.45	1.10	0.75	26.01	35.17	1.20	1.08	0.08	0.17	0.01	0.0011	"
49	0.44	1.13	0.79	25.68	35.11	1.15	1.16	0.09	0.19	0.53	0.0014	"

TABLE 6

Spec. No.	Test results: Creep fracture strength (kgf/mm^2) Condition (A)	Condition (B)	Resistance to thermal shock (times)	Resistance to carburizing (C content increment, %) Layer 1	Layer 2	Remarks
41	111	91	170	0.85	0.44	Invention
42	114	96	180	0.87	0.47	"
43	119	100	—	1.00	0.51	"
44	129	114	180	1.02	0.54	"
45	80	73	150	1.61	0.92	Comparison
46	95	82	150	1.23	0.66	"
47	64	57	110	1.04	0.56	"
48	100	83	140	1.29	0.74	"
49	58	54	100	1.03	0.57	"

EXAMPLE 4

Of the alloy specimens shown in Table 7, Specimens No. 50 to No. 53 are according to the invention and contain Ti, Al and Mo within the ranges of about 0.04 to 0.50% Ti, about 0.07 to 0.50% Al and about 0.2 to 0.8% Mo. Of Specimens No. 54 to No. 58 prepared for comparison, Specimen No. 54 is a HP material containing Nb, Mo and W (but free from any of N, Ti, Al and B), and Specimens No. 55 to No. 58 contain N, Ti, Al and B, the content of Ti or Al being outside the range specified by the invention.

Table 8 shows the results of creep fracture test, thermal shock resistance test and carburizing resistance test.

For the same reason given in Example 3, the iron-nickel-chromium alloys of this invention prepared in this example are lower than those in Examples 1 and 2 in respect of creep fracture strength and thermal shock resistance, but are much superior in high-temperature creep fracture strength and thermal shock resistance to the Nb-, W- and Mo-containing HP material, i.e. Specimen 55, which is considered to be higher than other conventional alloys in high-temperature creep fracture strength and also to the other comparison alloys.

Due to the synergistic effect of Ti and Al, the iron-nickel-chromium alloys of the invention have higher carburizing resistance than the comparison alloys.

TABLE 7

Spec. No.	C	Si	Mn	Cr	Ni	Nb + Ta	W	Mo	N	Ti	Al	B	Remarks
	Chemical compositions of alloy specimens (wt. %)												
50	0.45	1.27	0.73	25.71	35.82	1.10	1.12	0.45	0.08	0.18	0.15	0.0018	The invention
51	0.44	1.22	0.69	25.63	35.24	1.21	1.10	0.40	0.07	0.17	0.17	0.0022	"
52	0.43	1.28	0.65	25.95	36.07	1.25	1.06	0.39	0.10	0.09	0.12	0.0021	"
53	0.45	1.20	0.75	25.77	35.26	1.27	1.02	0.41	0.09	0.07	0.14	0.0017	"
54	0.42	1.20	0.71	26.12	35.37	1.29	1.10	0.42	—	—	—	—	Comparison
55	0.43	1.27	0.77	26.15	35.09	1.17	1.16	0.45	0.08	0.02	0.12	0.0011	"
56	0.44	1.12	0.75	26.13	34.91	1.25	1.14	0.37	0.09	0.56	0.10	0.0017	"
57	0.45	1.15	0.70	26.11	35.21	1.21	1.27	0.40	0.10	0.17	0.01	0.0012	"
58	0.44	1.10	0.67	25.78	35.20	1.15	1.10	0.45	0.10	0.19	0.54	0.0027	"

TABLE 8

	Test results					
	Creep fracture strength (kgf/mm^2)		Resistance to thermal shock	Resistance to carburizing (C content increment, %)		
Spec. No.	Condition (A)	Condition (B)	shock (times)	Layer 1	Layer 2	Remarks
50	117	96	180	0.81	0.42	Invention
51	121	102	180	0.83	0.45	"
52	131	105	—	0.95	0.48	"
53	136	121	190	0.97	0.51	"
54	85	77	160	1.53	0.87	Comparison
55	101	86	160	1.17	0.63	"
56	67	60	110	0.99	0.53	"
57	105	87	150	1.23	0.70	"
58	61	57	110	0.98	0.54	"

The heat resistant cast iron-nickel-chromium alloy of this invention is thus exceedingly superior to the conventional HP materials in respect of high-temperature creep fracture strength and resistance to thermal shock. Especially when high resistance to carburizing is required of the iron-nickel-chromium alloy, the alloy can be improved in this property while minimizing the reduction of the high-temperature creep fracture strength and thermal shock resistance by incorporating Ti and Al into the alloy in amounts within the ranges specified by the invention.

Accordingly the present iron-nickel-chromium alloy is well suited as a material for various apparatus and parts for use at temperatures above 1000° C., for example, for ethylene cracking tubes and reforming tubes in the petrochemical industry or for hearth rolls and radiant tubes in iron and steel and related industries.

The scope of the invention is not limited to the foregoing description, but various modifications can be made with ease by one skilled in the art without departing from the spirit of the invention. Such modifications are therefore included within the scope of the invention.

What is claimed is:

1. A heat resistant cast iron-nickel-chromium alloy consisting essentially of the following components in the following proportions in terms of % by weight:

C—0.3-0.6,
O<Si≦2.0,
O<Mn≦2.0,
Cr—20-30,
Ni—30-40,
Nb+Ta 0.3-1.5,
W—0.5-3.0,
N—0.04-0.15,
B—0.0002-0.004,
Ti—0.04-0.50 and
Al—0.02-0.50,

the balance being substantially Fe.

2. A heat resistant cast iron-nickel-chromium alloy as defined in claim **1** wherein 0.04 to 0.15% by weight of Ti and 0.02 to 0.07% by weight of Al are contained.

3. A heat resistant cast iron-nickel-chromium alloy consisting essentially of the following components in the following proportions in terms of % by weight:

C—0.3-0.6,
O<Si≦2.0,
O<Mn≦2.0,
Cr—20-30,
Ni—30-40,
Nb+Ta 0.3-1.5,
W—0.5-3.0,
N—0.04-0.15,
B—0.0002-0.004,
Ti—0.04-0.50,
Al—0.02-0.50 and
Mo—0.2-0.8,

the balance being substantially Fe.

4. A heat resistant cast iron-nickel-chromium alloy as defined in claim **3** wherein 0.04 to 0.15% by weight of Ti and 0.02 to 0.07% by weight of Al are contained.

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